**NATIONAL TRANSPORTATION SAFETY BOARD**
Office of Research and Engineering
Washington, D.C. 20594

May 14, 2018

# Video Study

**NTSB Case Number:**
**CEN17FA127**

## A. ACCIDENT

| | |
|---|---|
| Location: | Chalmers, Indiana |
| Date: | March 14, 2017 |
| Time: | 1546 EDT |
| Aircraft: | MD Helicopters 369FF helicopter |

## B. AUTHOR


Dan T. Horak
NTSB


## C. ACCIDENT SUMMARY

On March 14, 2017, at 1546 eastern daylight time, an MD Helicopters 369FF helicopter, N530KD, impacted terrain during a powerline construction flight. The pilot was fatally injured and the helicopter was destroyed. The helicopter was registered to a private individual and operated by Rogers Helicopters, Inc., under the provisions of Title 14 *Code of Federal Regulations* Part 133 as an external load operation. Visual meteorological conditions prevailed at the time of the accident and no flight plan had been filed.

The purpose of the flight was to thread a braided metal sock line through the tower structure and pull the sock line to the next tower. The helicopter was equipped with a side pull hook assembly and a cargo hook. The cargo hook was attached to a 50-ft long line and grappling hook. The grappling hook was connected to a large metal needle which enabled the pilot to thread the sock line through the eye of the tower.

## D. DETAILS OF INVESTIGATION

The purpose of this study was estimating the orientation of the helicopter and the orientation and magnitude of the force vector that the long line was applying on the helicopter at the time of the accident. The helicopter was captured on a video acquired by a hand-held smartphone located near the tower through which the helicopter was attempting to thread the sock line. The video had 1920x1080 resolution and frame rate of 30 fps.

Camera Calibration

Figure 1 shows an aerial view of the accident area. It shows Tower 39, near which the helicopter crashed when threading the sock line through it, and Tower 38, that was already threaded. The sock line extended from Tower 38 to the helicopter that was near Tower 39 and was pulling the sock line. The dimensions of the towers were known and were used for calibrating the camera.


**Figure 1. Aerial View of the Accident Area**

The mathematical model of camera optics requires seven parameters. Three are the X, Y and Z camera location coordinates. Three are the yaw, pitch and roll camera orientation angles, and the seventh parameter is the camera horizontal field of view

(HFOV). None of the seven parameters were known or measured. Therefore, all seven had to be estimated.

The estimation was based on references that were visible both in aerial images and in video frames. These references were points on Tower 39 and a telephone pole on Road S 150 E, not visible in Figure 1. Figure 2 shows a frame from the video that shows Tower 39 and the pole. It also shows the sock line, the long line and the needle that the helicopter used for power line threading. The needle is equipped with two hooks. One is at its leading edge and the other near is center. In Figure 2, the long line is attached to the hook near the center.

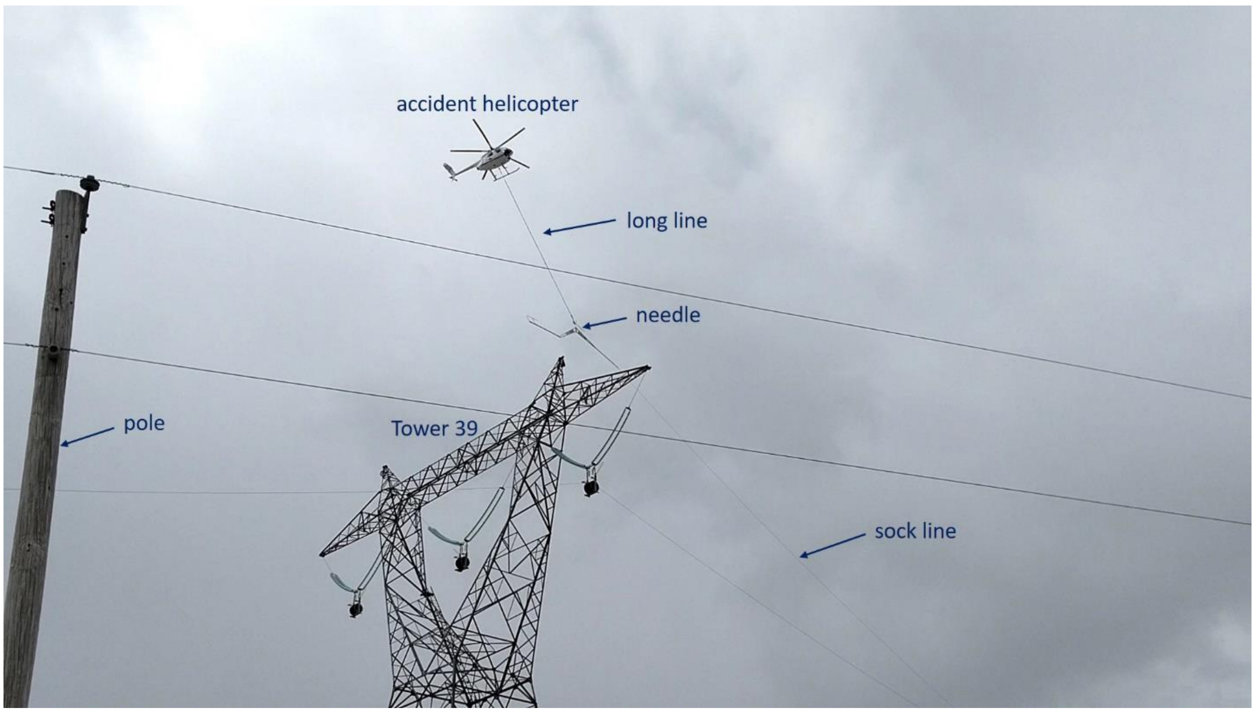


**Figure 2. Frame from the Video Showing Tower 39**

A computer program that simulates camera optics was used to project the references onto a frame from the video in an iterative process in which the seven parameters were varied so as to align the projected references with their images. When the projected references were aligned optimally with their images in the frame, values of the seven parameters were their optimal estimates. At that point, the model of the camera optics was calibrated.

<u>Estimation of Helicopter Location and Orientation</u>

Helicopter locations and orientation angles in ground coordinates were estimated with the calibrated camera optics model. A wireframe model of the MD 369FF helicopter was constructed consisting of points on its nose, tail, rotor hub, and landing skids. The camera model was then used to project the wireframe model onto a frame from the video. The wireframe model location and orientation angles were then varied iteratively until it coincided optimally with the image of the helicopter in the video frame. At that time, the wireframe model location and orientation were the optimal estimates of the location and orientation of the accident helicopter at the time the analyzed video frame was acquired.

Four video frames were analyzed in detail. Their numbers in the video were 5210, 5285, 5315 and 5325. Frames 5249, 5310 and 5373 were not analyzed in detail but are reproduced below because they show significant events as this accident event was developing. The video had constant frame rate of 30 frames/second, which allowed assigning time to each frame. Frame 5285 was acquired at a time considered the onset of the accident event and, therefore, was assigned time T=0.0 seconds. The other frames were assigned times relative to Frame 5285.

Frame 5210, shown in Figure 3, was acquired at time -2.5 seconds, 2.5 seconds before Frame 5285 was acquired. It was analyzed to illustrate the situation before the events resulting in the crash started at time 0.0 seconds.

Frame 5249 is shown in Figure 4. It was acquired at time T=-1.2 seconds, approximately when the leading end of the needle contacted the tower for the first time. The force that the long line applied on the helicopter at that time was still primarily due to the weight of the sock line.

Frame 5285, shown in Figure 5, was acquired at time T=0.0 seconds. It shows the helicopter at the approximate time when the forces applied on it by the long line are about to transition from being due to the weight of the sock line to being caused by the entanglement of the needle with the tower. It is considered the beginning of the events that resulted in the crash.

Frame 5310, shown in Figure 6, was acquired at time T=0.83 seconds. It displays the helicopter right after the hook near the center of the needle became entangled in the tower. It is possible that the hook at the front of the needle was also entangled at this time. It cannot be determined from the video whether one or both hooks were entangled. The entanglement changed the forces that the long line applied on the helicopter. The helicopter became tethered to the tower and its distance from the entangled hook near the center of the needle was fixed to the length of the long line. The force that the long line applied on the helicopter was primarily the reaction to the helicopter rotor thrust.

It is believed that the situation was not recoverable past time T=0.83 seconds. One second later, at time T=1.83 seconds, the video shows the helicopter in a loss of control situation and descending toward ground impact. It impacted the ground at time T=7.5 seconds.

Frame 5315, acquired at time T=1.0 seconds and Frame 5325, acquired at time T=1.33 seconds, are shown in Figure 7 and Figure 8, respectively. They show the helicopter past the time of no recovery, tethered to the tower. The hook near the center of the needle fractured and separated from the needle at approximately time T=1.33 seconds.

**Figure 3. Video Frame No. 5210 (T=-2.5 seconds)**

**Figure 4. Video Frame No. 5249 (T=-1.2 seconds)**

**Figure 5. Video Frame No. 5285 (T=0.0 seconds)**

**Figure 6. Video Frame No. 5310 (T=0.83 seconds)**

**Figure 7. Video Frame No. 5315 (T=1.0 seconds)**

**Figure 8. Video Frame No. 5325 (T=1.33 seconds)**


**Figure 9. Detail from Video Frame No. 5373 (T=2.93 seconds)**

Figure 9 shows a detail from Frame 5373, acquired at time T=2.93 seconds. The hook that was attached near the center of the needle is visible separated from the needle and from the grappling hook at the end of the long line.

The detailed analysis of frames 5210, 5285, 5315 and 5325 resulted in estimates of the location of the helicopter and of its three orientation angles, yaw, pitch and roll. Frames 5210 and 5285 display the helicopter before it became entangled in the tower. It was known that for these two frames, the sock line extended from Tower 38 to Tower 39. Therefore, the yaw orientations of both the sock line and the long line were along the tower-to-tower direction. Consequently, once the location of the helicopter was known, it was possible to estimate the pitch angle of the sock line and of the long line with respect to ground. Frames 5310 and 5325 show the situation after the needle became entangled and the yaw orientation of the long line could no longer be assumed to be in the tower-to-tower direction. Figures 10, 11, 12 and 13 show the orientations of the helicopter in ground coordinates at times corresponding to the four analyzed frames. Figures 10 and 11, corresponding to frames 5210 and 5285, also show the orientation of the long line. In Figures 10, 11, 12 and 13, the X coordinate is along the direction from Tower 39 to Tower 38, and the Z coordinate is the estimated altitude of the helicopter above the ground, while the origins of the X and Y coordinates were set to be near the helicopter.

<u>Sock Line and Long Line Forces</u>

The force that the long line applied on the helicopter at the times frames 5210 and 5285 were acquired were due to the weight of the sock line. These forces were estimated as described next.

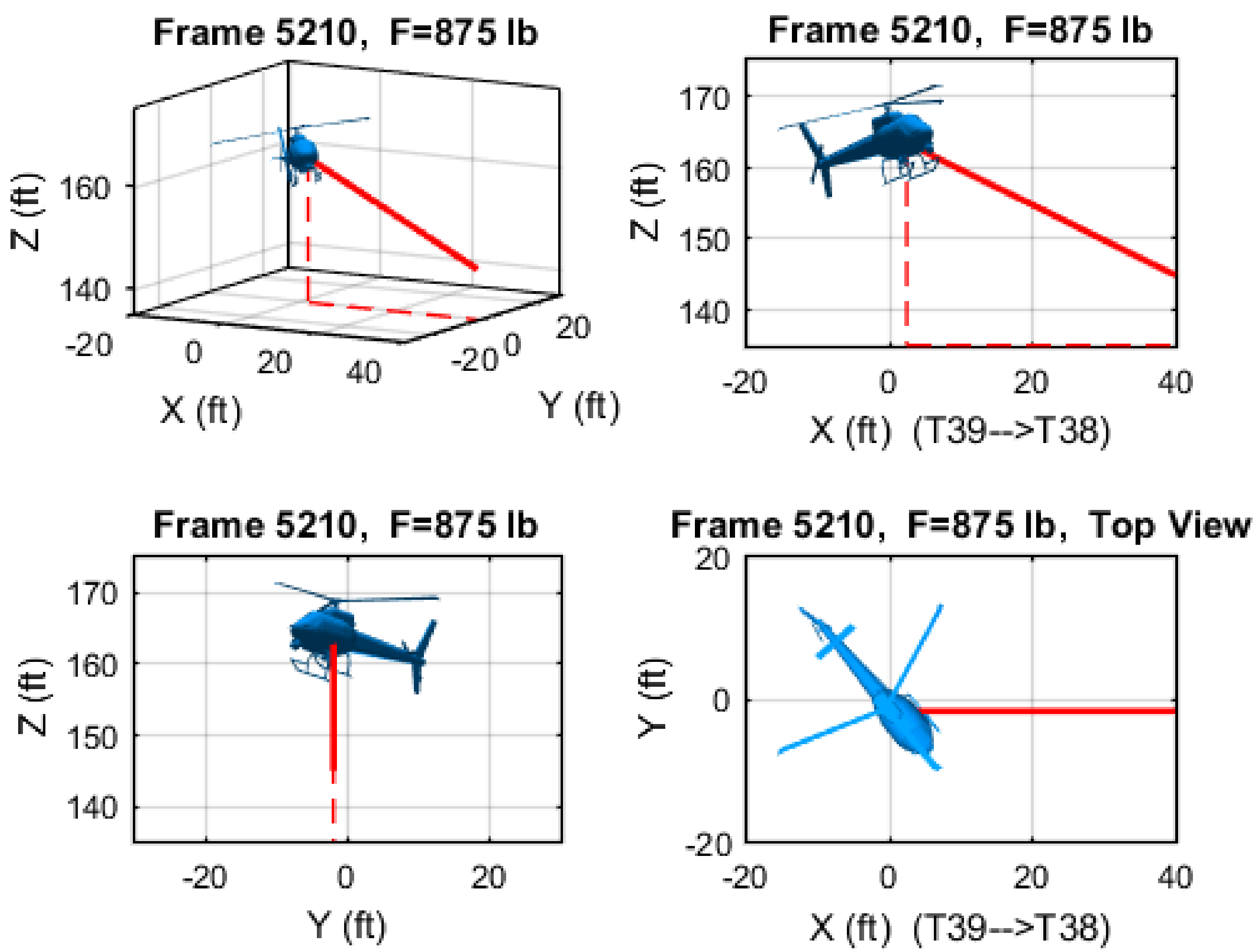


**Figure 10. Helicopter and Long Line (Frame 5210, T=-2.5 seconds)**

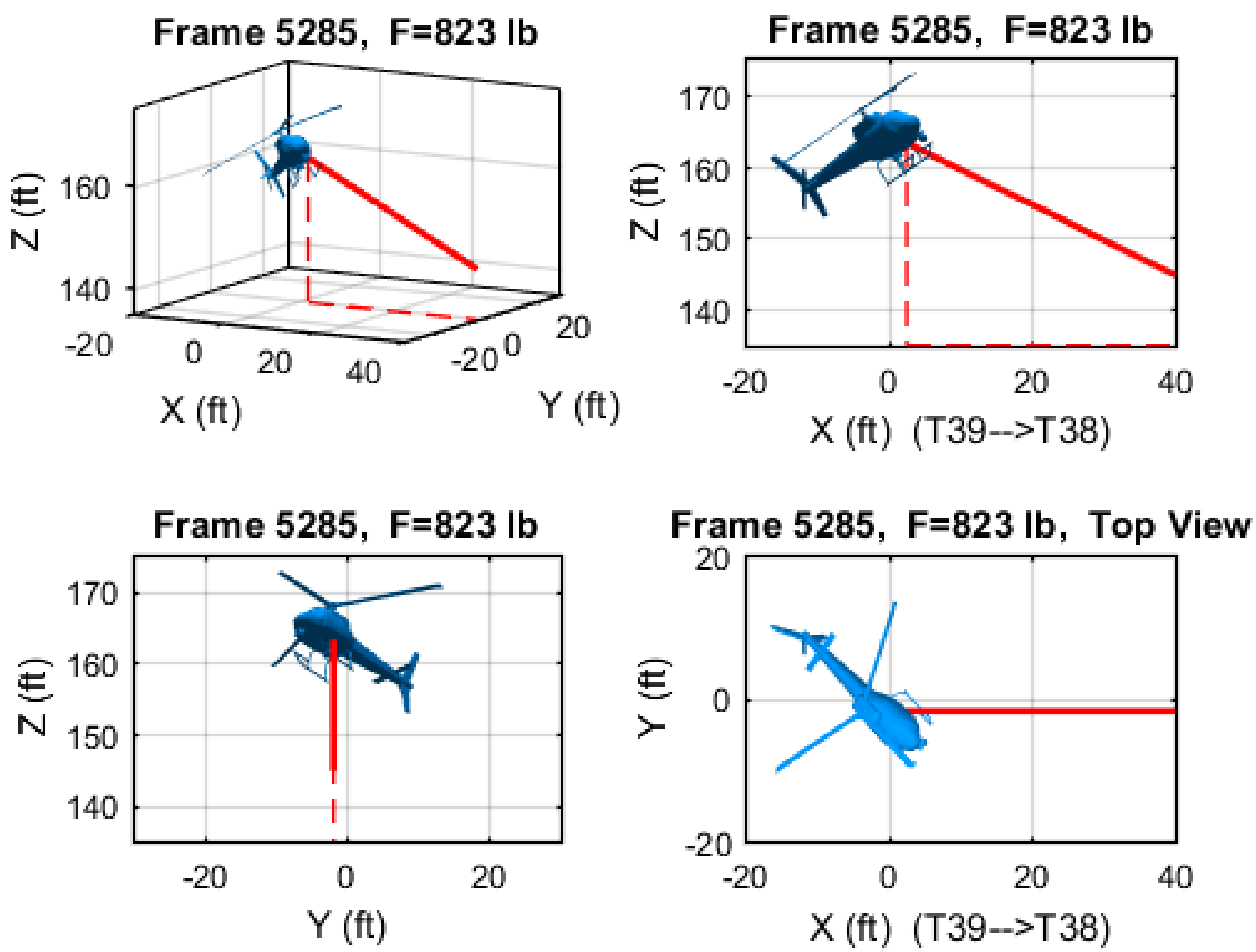


**Figure 11. Helicopter and Long Line (Frame 5285, T=0.0 seconds)**

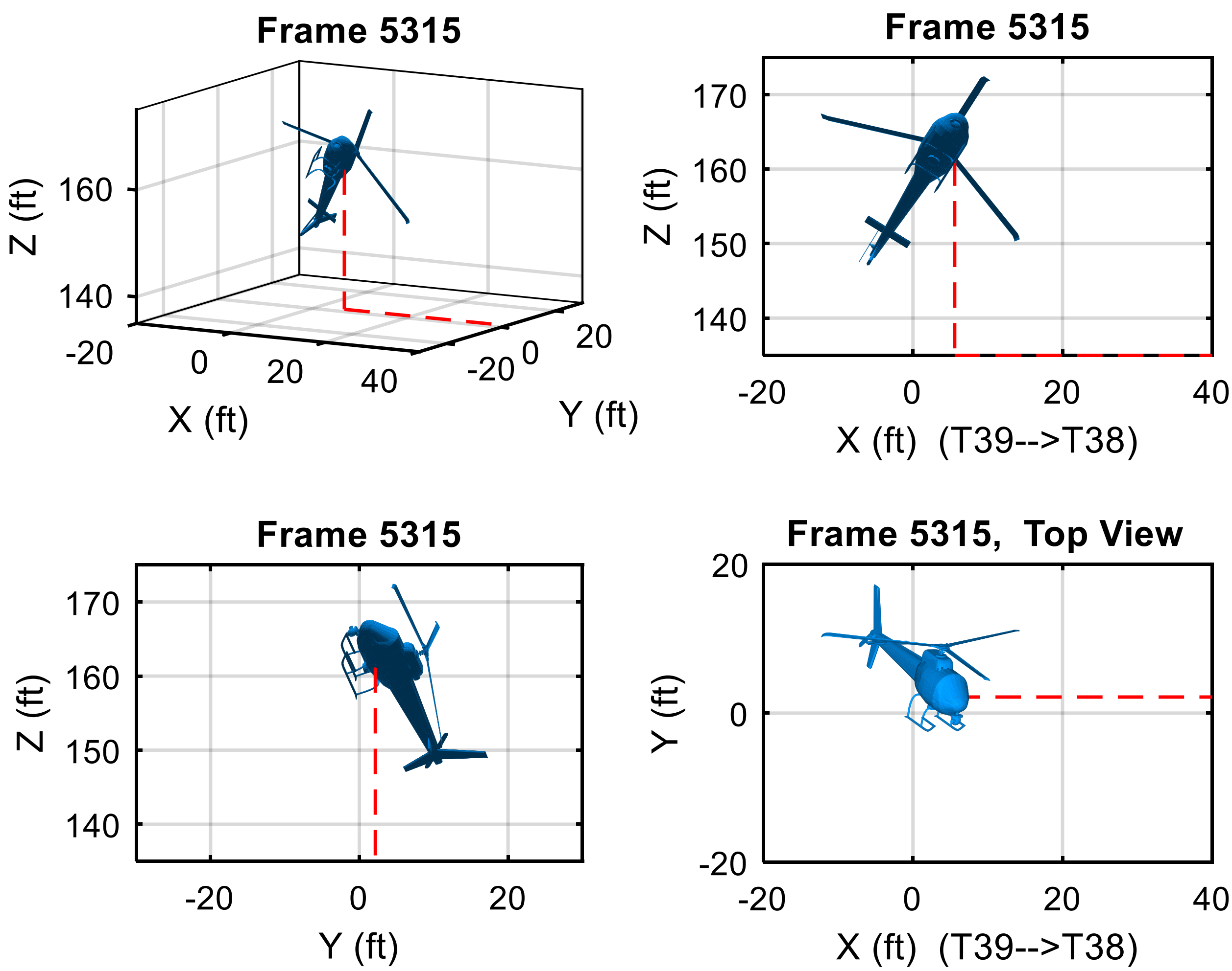


**Figure 12. Helicopter Orientation (Frame 5315, T=1.0 seconds)**

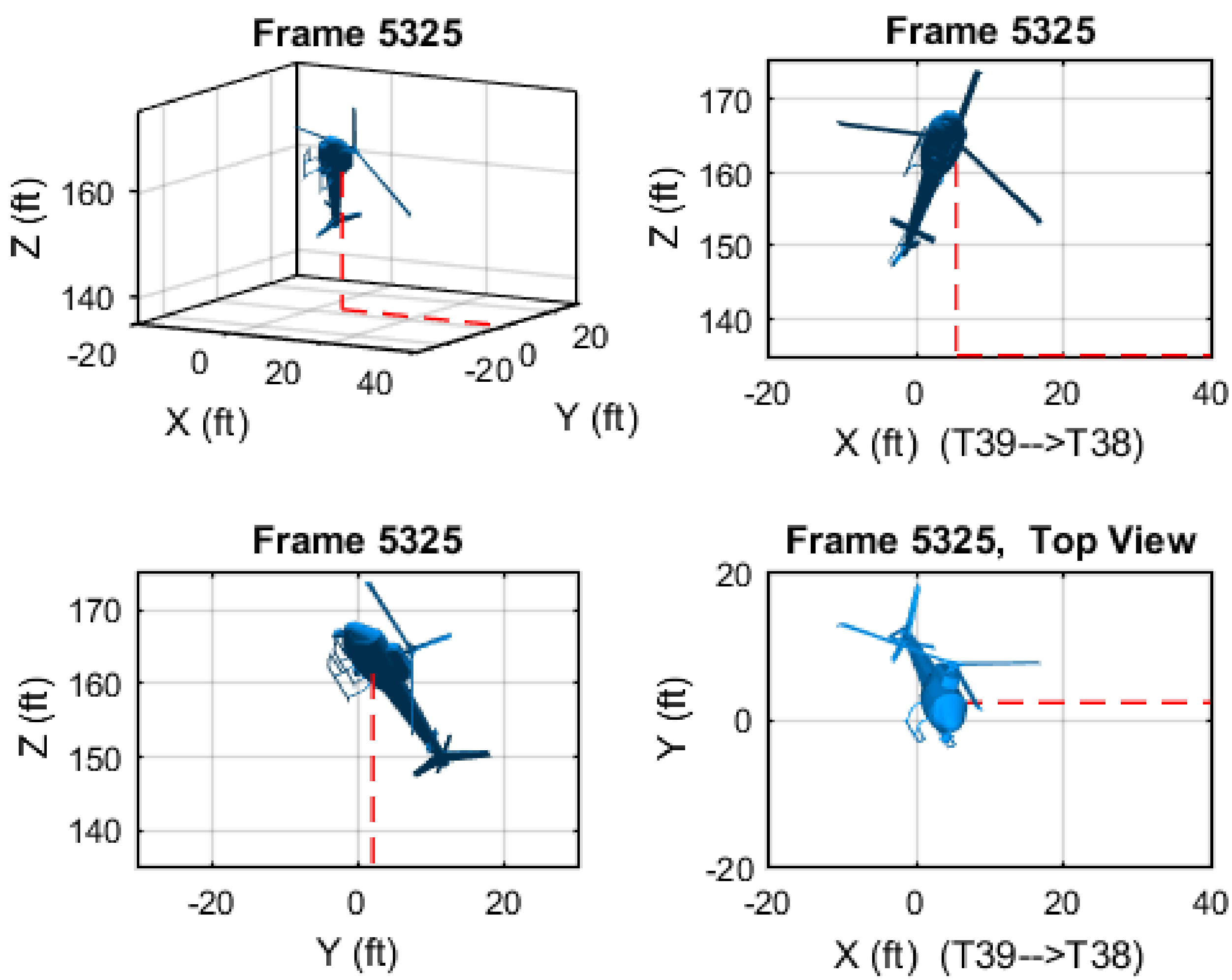


**Figure 13. Helicopter Orientation (Frame 5325, T=1.33 seconds)**

The sock line, extending from Tower 38 to the needle, assumes a catenary shape under the loading of its own weight. This shape, a hyperbolic cosine, is described by $Z_{sock}=a\times\cosh(X/a)$, where $X$ is the distance along the span (the distance between the sock line end supports) and $Z_{sock}$ is the vertical coordinate of the catenary at location $X$. Parameter $a$ must be solved for iteratively because of the nonlinearity of the catenary expression. Once parameter $a$ is known, it is possible to compute the maximum sag of the sock line and the force it applies on the attachment point to the needle.

In this specific case, since the pitch angle of the sock line at the needle is known from video analysis of frames 5210 and 5285, the force the sock line applies on the attachment point can be estimated without considering the catenary shape. The attachment point must support one half of the weight of the sock line so that the vertical component of the sock line force at the attachment point is known. Since the pitch angle of the sock line is known, the total force can be estimated by assuming that the length of the sock line is equal to the span, computing the approximate weight of one half of the sock line, and dividing it by the sine of the pitch angle. However, this method has two disadvantages, It approximates the length of the sock line by the span, and it does not estimate the sag of the sock line. Without knowing the sag, it cannot be assumed that the sock line did not touch the ground between the two towers, making the vertical force at the attachment point assumption invalid.

To avoid these two approximations, the problem was solved as a catenary case. There were two unknows, the length of the sock line between Tower 38 and the attachment point to the needle, and the catenary parameter $a$. The span could be measured in Google Earth as approximately 1160 feet. A computer program was written that in an outer loop increased the assumed length of the sock line by one foot in each pass starting from 1170 feet. An inner loop then calculated the catenary parameter $a$ for the assumed length of the sock line.

Once parameter $a$ was known, it was possible to estimate the pitch angle of the catenary shape at the needle. The assumed length of the sock line that generated the best match between the sock line pitch angle from video analysis and the one from catenary computation was the correct assumed length. With the correct length known, it was possible to estimate the force that the sock line was applying on the attachment point with the needle.

Figure 14 shows a force diagram at the junction of the sock line, the long line and the needle. From the balance of horizontal force components, the long line force, $F$, can be estimated as $F=T\times\cos\beta/\cos\alpha$. The force that the long line applies on the helicopter is the reaction to force $F$ shown in Figure 14 and its direction is opposite to the direction shown in Figure 14. Figures 10 and 11 list the force $F$ that the long line applies on the helicopter and show the orientation of the force vector as the solid red line. The horizontal broken red line in the figures is the direction from the helicopter to Tower 38. Figures 12 and 13 do not list the force or show the orientation of the force vector because at the times corresponding to these figures, the helicopter was already tethered to the tower and the catenary analysis did not apply. The values of $F$ listed in the figures 10 and 11 are the nominal values and their accuracy is estimated to be ±15%.

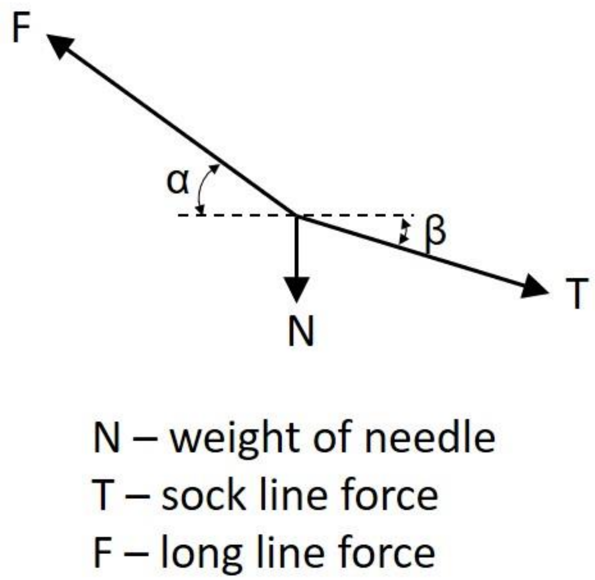


**Figure 14. Force Diagram at the Needle**

<u>Comments</u>

The long line force applied on the helicopter before the accident event started was 875 lb or less (see Figure 10 and Figure 11). The long line attachment to the helicopter was rated at 1900 lb, a force considered safe for the helicopter. Therefore, it is unlikely that the long line force applied on the helicopter before the needle contacted the tower, less than half the rated force, caused this accident.

The video shows that shortly before time T=-1.2 seconds (see Figure 4), when the needle first contacted the tower, the helicopter started moving backward. Figures 10 and 11 show that the helicopter yaw angle was about 45º with respect to the tower at that time. It is possible that the pilot decided to move backward assuming it would move the needle away from the tower. However, that strategy did not work as expected. Figure 2 shows that in normal operation, the needle is oriented vertically. Figure 4 shows that as the helicopter moved backward, the needle rotated (rolled) and was no longer oriented vertically. The rotation moved the leading edge of the needle closer to the tower rather than away from it and at time T=-1.2 seconds it contacted the tower. Further backward movement then pulled the hook near the center of the needle into contact with the tower and it led to tethering of the helicopter to the tower.

## E. <u>CONCLUSIONS</u>

Video captured by a hand-held smartphone was used to estimate the locations and orientations of a helicopter that crashed while threading power lines. The video was also used to estimate the orientation angle of the long line and of the sock line that the helicopter was pulling. Catenary analysis of the sock line shape was then used for estimating the force that the long line applied on the helicopter before the time it lost control. This force was estimated to be below 875 ±130 lb. The helicopter orientation and the orientation of the long line force vector were documented graphically.

The video revealed that the accident event started when the front end of the needle the helicopter was using for threading the sock line contacted the tower. The helicopter then moved backward and that motion moved the hook near the center of the needle into contact with the tower where the hook became entangled. The helicopter was tethered to the tower past that time and it lost control in about one second. It impacted the ground 7.5 seconds after the first needle contact with the tower.